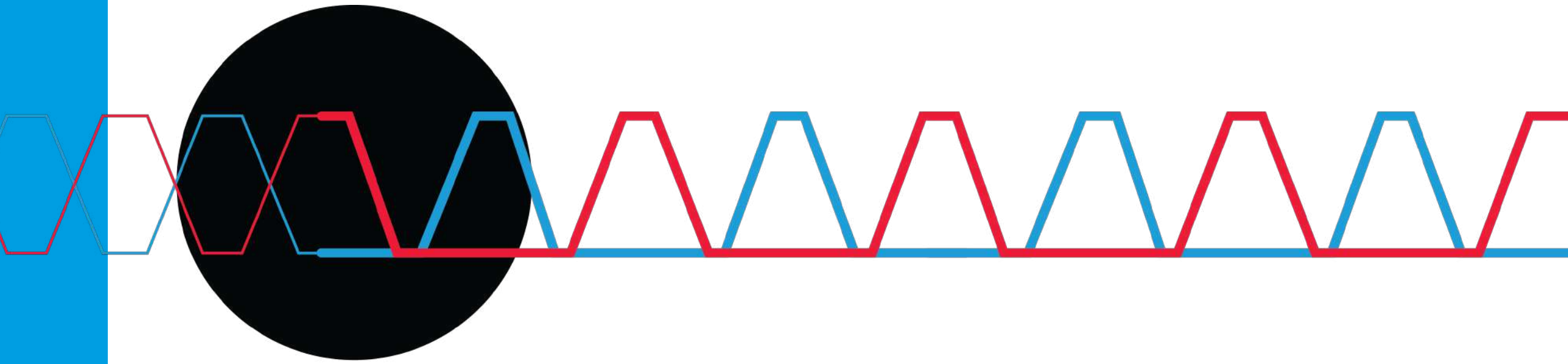

Pre-Switch, Inc.

Extending EV range

The Paradigm Shift: AI Soft-Switching for EV inverters

Contact:
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+4915121063411
Skype: Chris.Rocneanu
Info@pre-switch.com

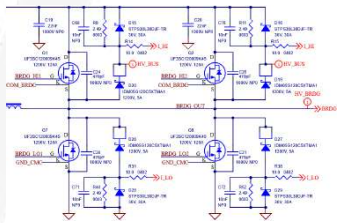
Technology

Pre-Switch solution

Embedded AI in FPGA

+

Reference Hardware



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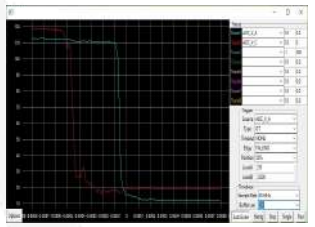
System Software



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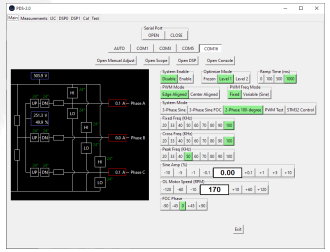
Development Tools

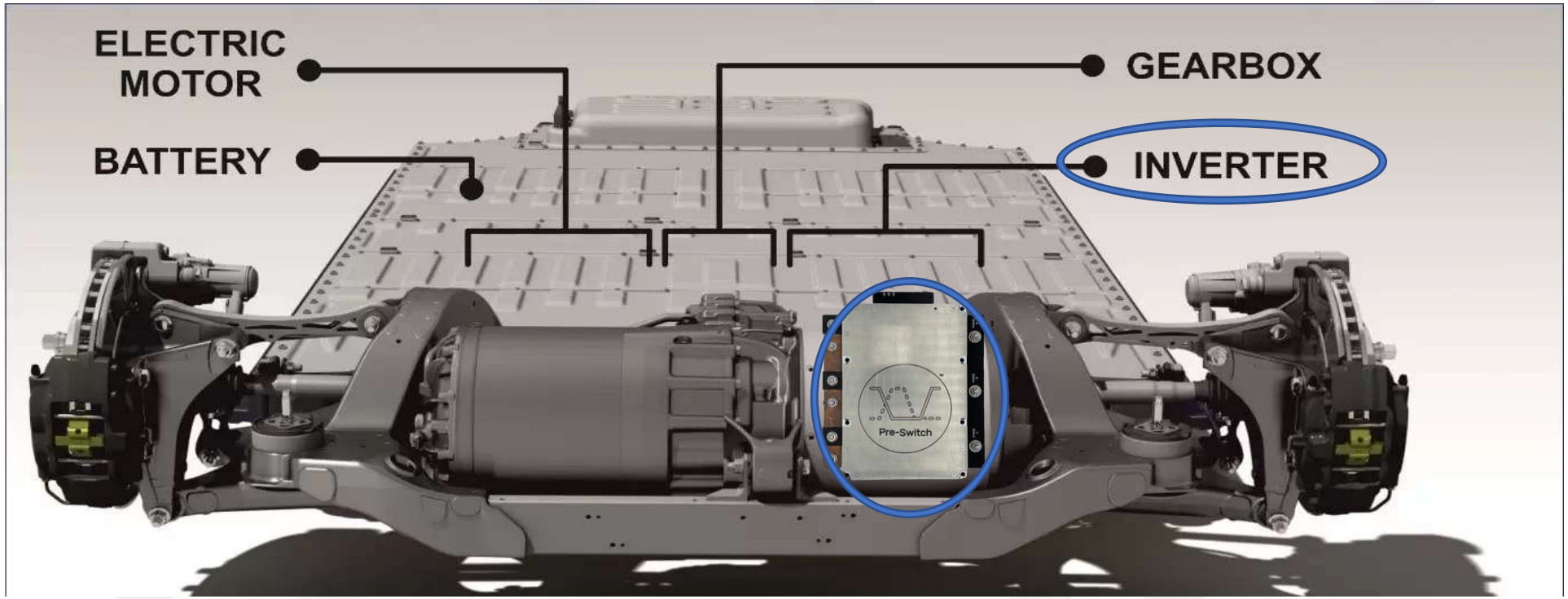


- Full soft-switching virtual eliminates transistor switching losses across all varying conditions
- Large efficiency gains for EV drivetrain inverter AND motor + other applications
- Lowest system costs and highest efficiency of any power conversion architecture
- Diverse proprietary IP, 1 US patent and corresponding filings in foreign countries, multiple inventions, trade secrets and development tools

Initial application

Replace today's non-differentiated inefficient EV inverter architecture

Many other applications to follow



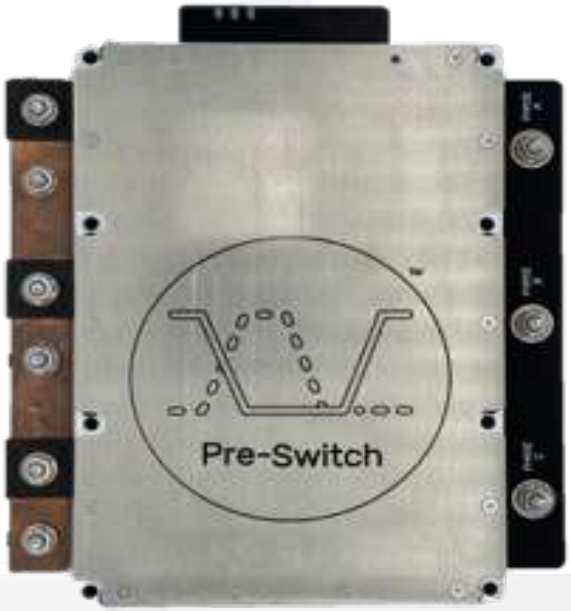
"All EV future EV inverters will need to use Soft-Switching"

(quoted from lead Audi Inverter design engineer)

Benefits

5-12 % more EV range or smaller battery

- Differentiated Inverter efficiency at all load points (low load, average, peak)
- Improves motor efficiency and reliability

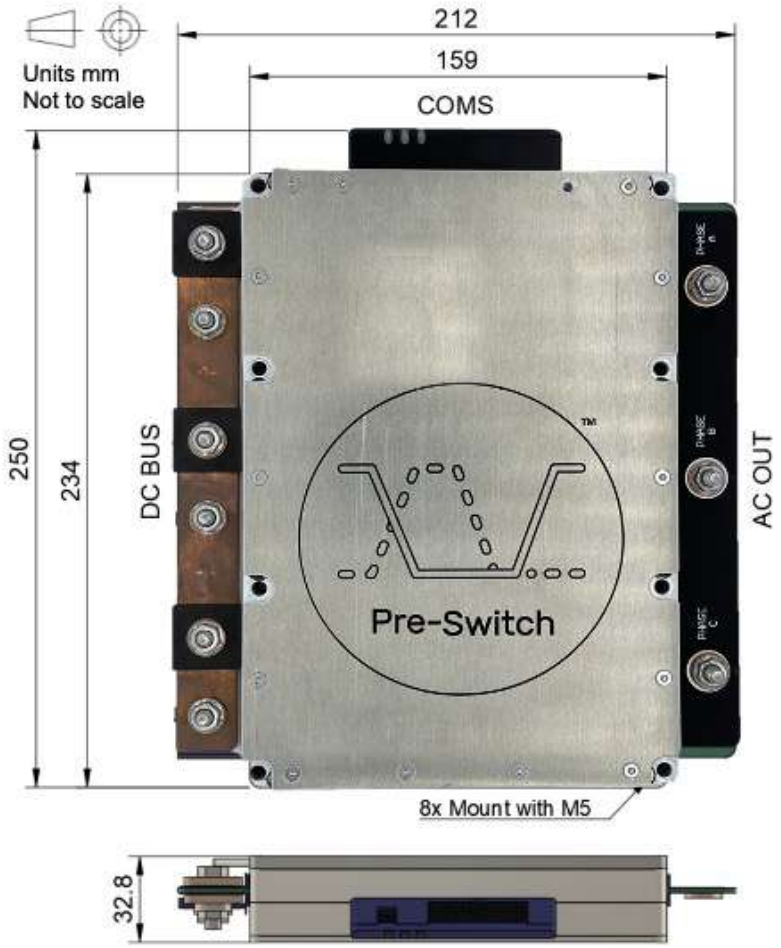


- Reduced SiC/IGBT transistors needed per amp delivered
- Shrinks DC link capacitor size and costs
- Permits IGBTs to nearly match SiC performance - bypassing SiC constraints
- Facilitates low-cost discrete transistors to replace heavy expensive power modules

Reduces costs and size

Performance

Pre-Switch CleanWave2 reference inverter



Parameter	Pre-Switch reference inverter	Present day EV Inverters
Architecture	AI Soft-Switched	Old hard-switched
Power	250kW	275kW
Voltage	500-900V	800V
Peak efficiency	>99.5%	98.5% est.
5% load efficiency	98.5%	92% est.
Switching frequency	100kHz	**12kHz**
improves motor efficiency	Yes	No
Audible Noise	No	Yes
Power density	>200kW/L	~39kW/L
Weight	<3kg	~8kg
Transistor die (qty)	(12) 9 mΩ	(48) 15 mΩ
Transistor type	Discrete SiC	SiC Power Module
Total transistor cost	$200 w/ARCP*	$385*
DC capacitor volume	18 mL	~500 mL
Estimated production cost	X	1.5-2X

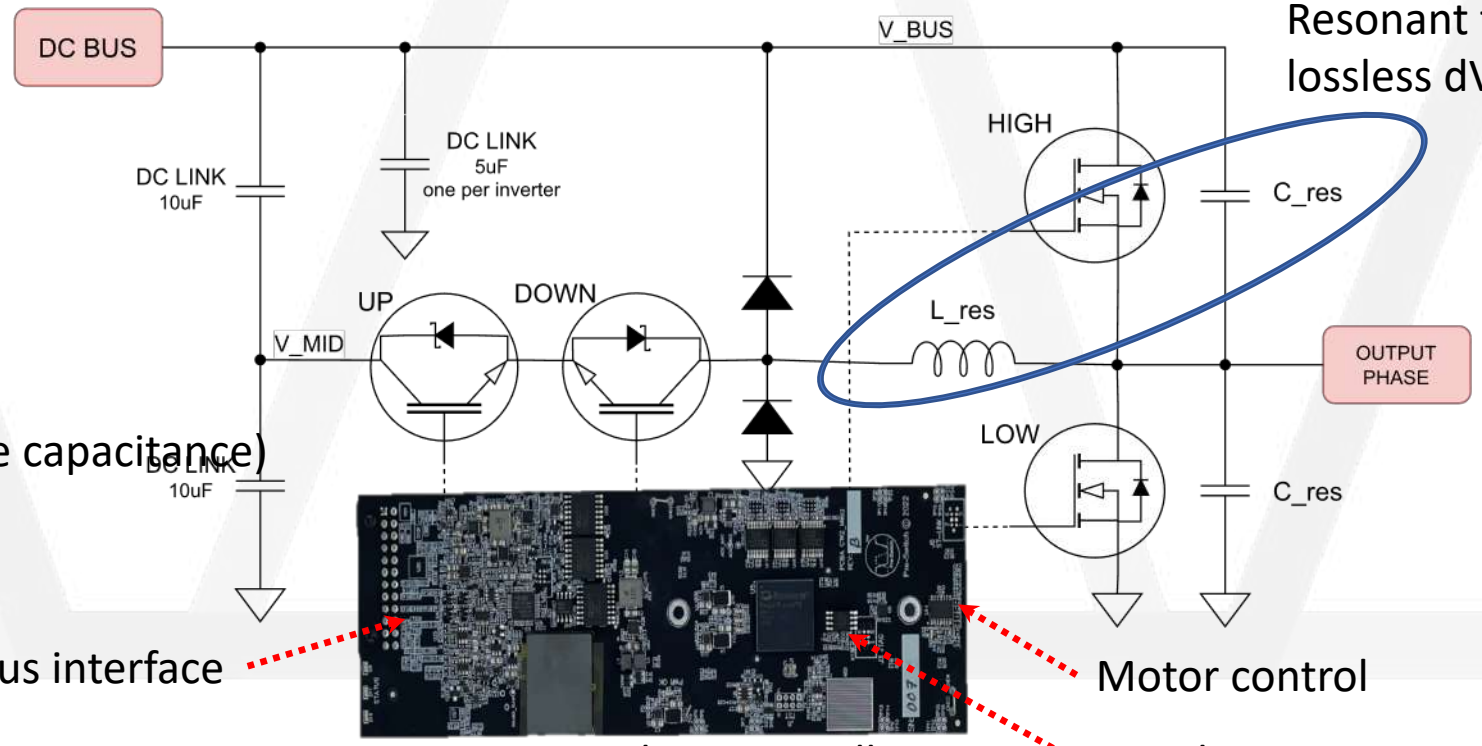
5-12% more range

Lower cost

* Based on estimated high volume 2026 automotive pricing

Architecture

- **Embedded AI real-time control, diagnostics, and safety for ARCP architecture**
  - **Patented control solved decades of instabilities and corner case exceptions**
- **Senses, learns, predicts, adjusts, protects and continually optimizes efficiency**

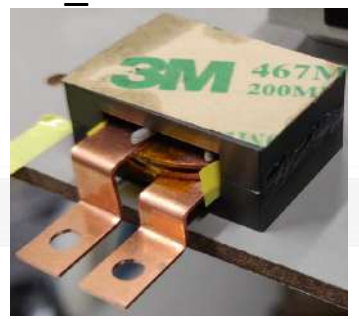


Resonant tank and
lossless dV/dt filter

C_res = 2 x 2.27nF
1210 ceramic NPo

330 nH
17nF (with device capacitance)

L_res =330nH



CAN bus interface

Motor control

Pre-Switch AI controller

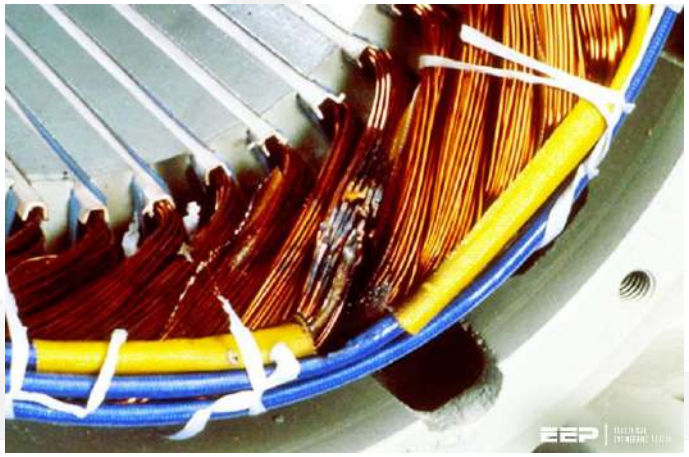
Pre-Flex IC

Fast edge speed solution

- Hard switched SiC increases transistor edge transition speeds for improved efficiency causing:
  - Excessive EMI
  - Destructive bearing currents in electric motors
  - Break down motor insulation
  - Voltage overshoot and ringing

- **Pre-Switch: Adjustable edge speeds using integrated lossless dV/dt filter**
  - Saves motor insulation
  - Eliminates bearing currents
  - Detects arcing in bearings and insulation
  - Significantly reduces inverter EMI

Ken Fonstad, ABB: "For a given motor voltage, the insulation stress increases as the rise time becomes shorter or the dV/dt value becomes larger."



Algorithm initial power up and first learning (Pre-Flex Gen 4)

Switching cycles 0-2 (Initial start-up/turn-on with unknown starting conditions):

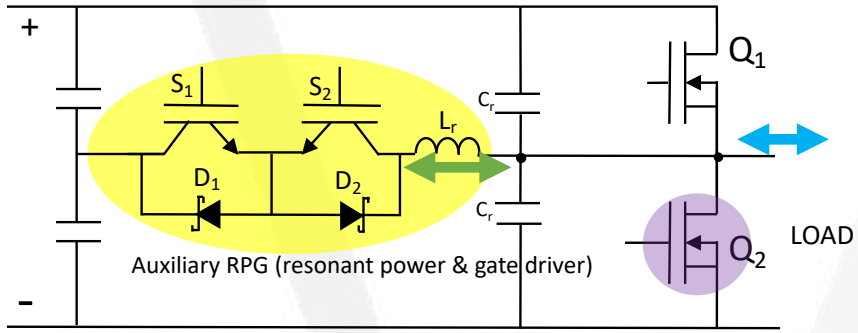
Cycle 0: Large resonant current to ensure soft-switching on first cycle

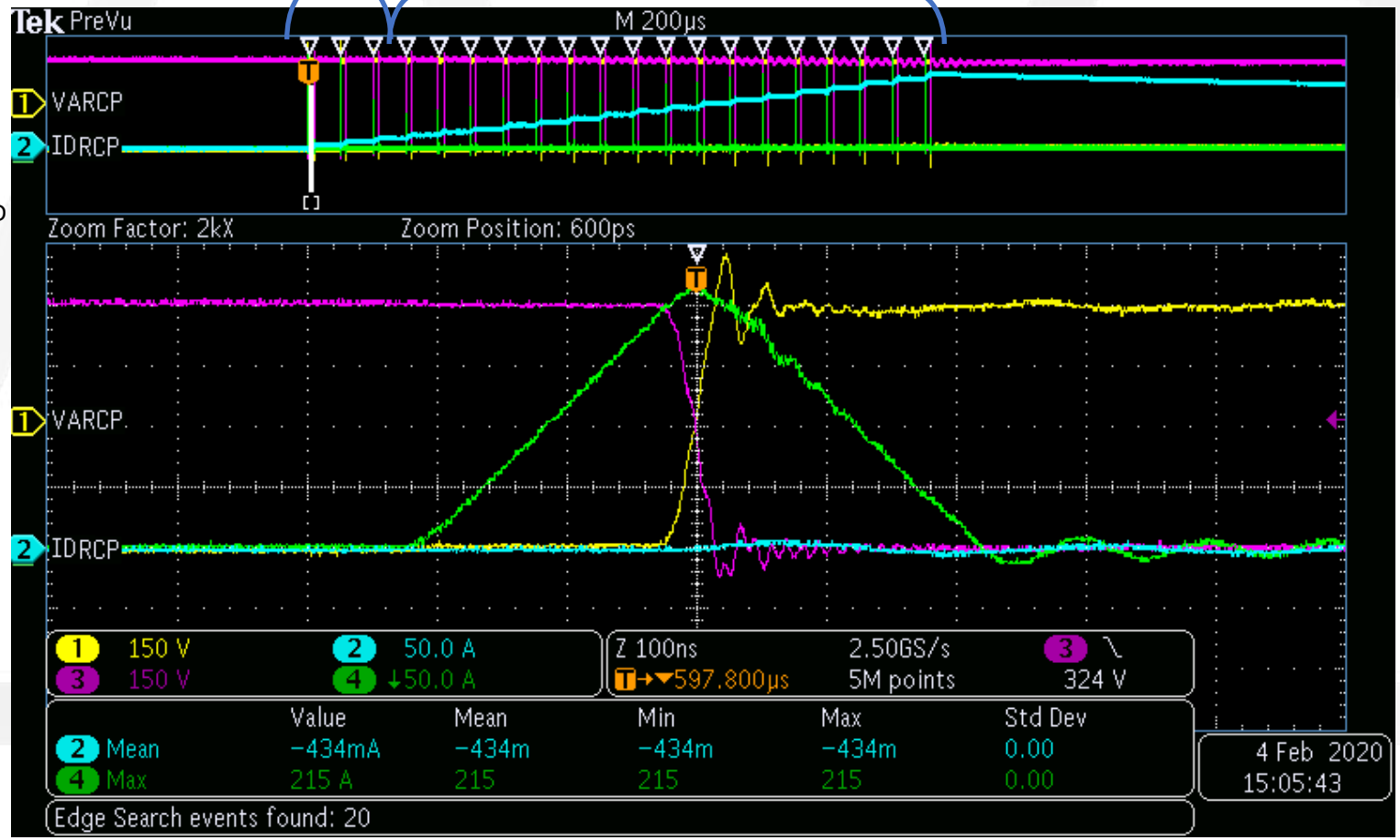
Cycle 1: Same large resonant current (first complete AI learning)

Cycle 2: First AI optimized switching cycle yields large adjustment

Switching cycles 2-19:

- Subsequent AI learning and prediction compensates for changing system conditions including load current
- Resonant inductor current increases with increasing load current
- Overshoot dramatically reduced





Green: L_r Resonant inductor current (varies with load)

Purple: Q_2 V_{ds} switch voltage (600V-0V)

Yellow: Aux + L_r Auxiliary circuit and inductor voltage (-300V to +300V)

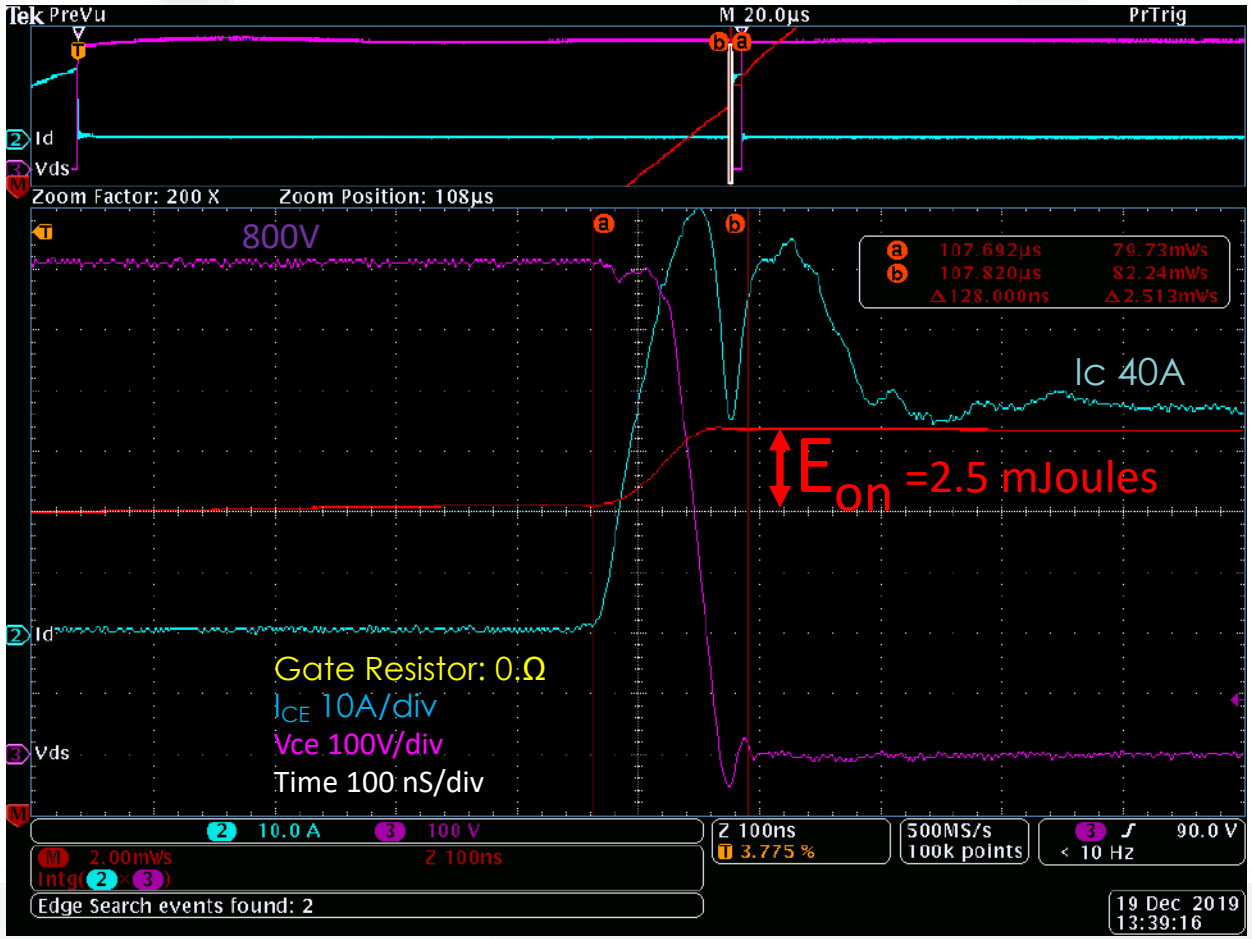
Blue: Load current varies (0-160A)

Click here for live demo

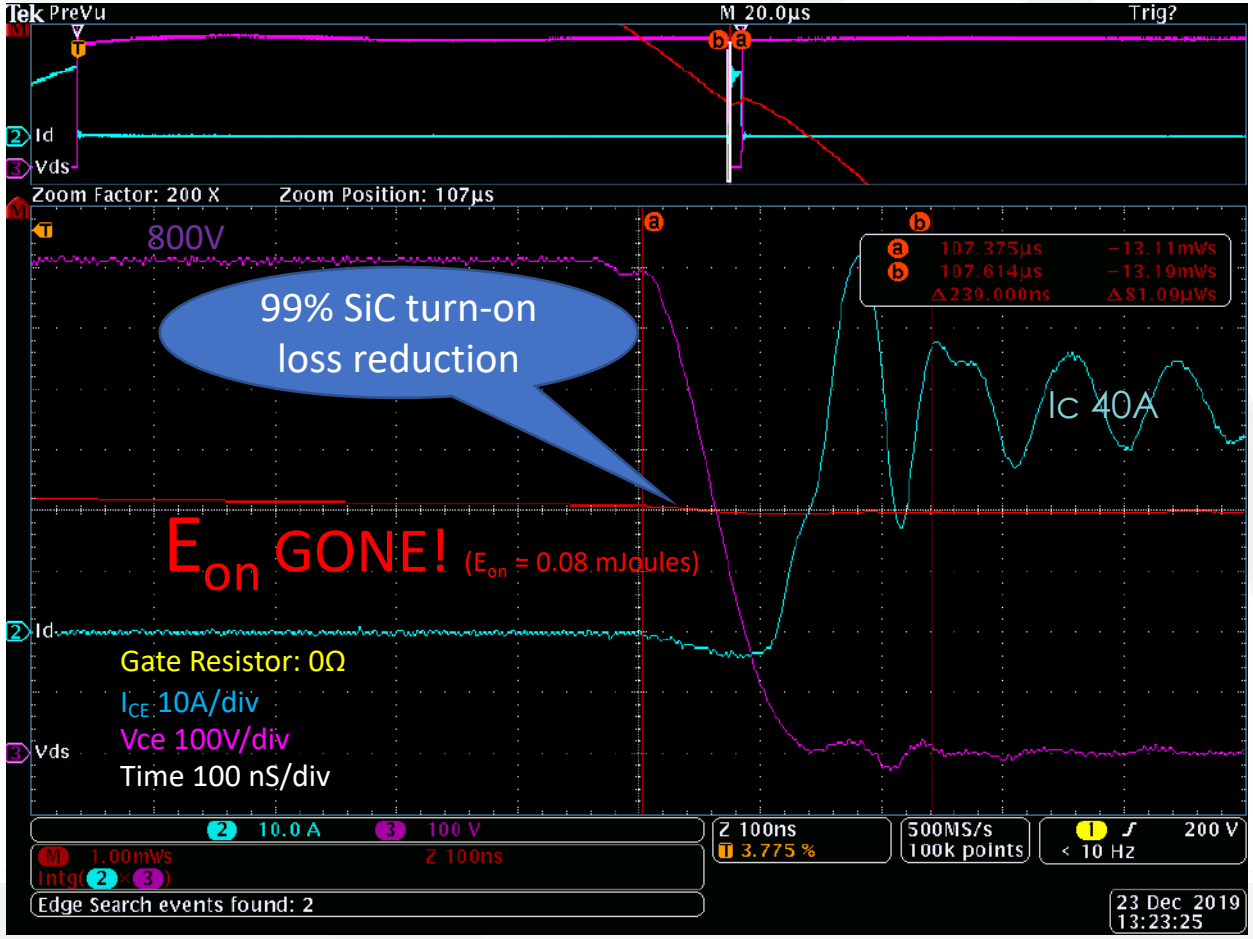
CleanWave200 600V, 20ms continuous, 10 kHz Fsw, 3 parallel SiC MOSFETs varying load current for sine wave output

Eliminates switching losses (SiC E_{on} turn-on)

Hard Switched



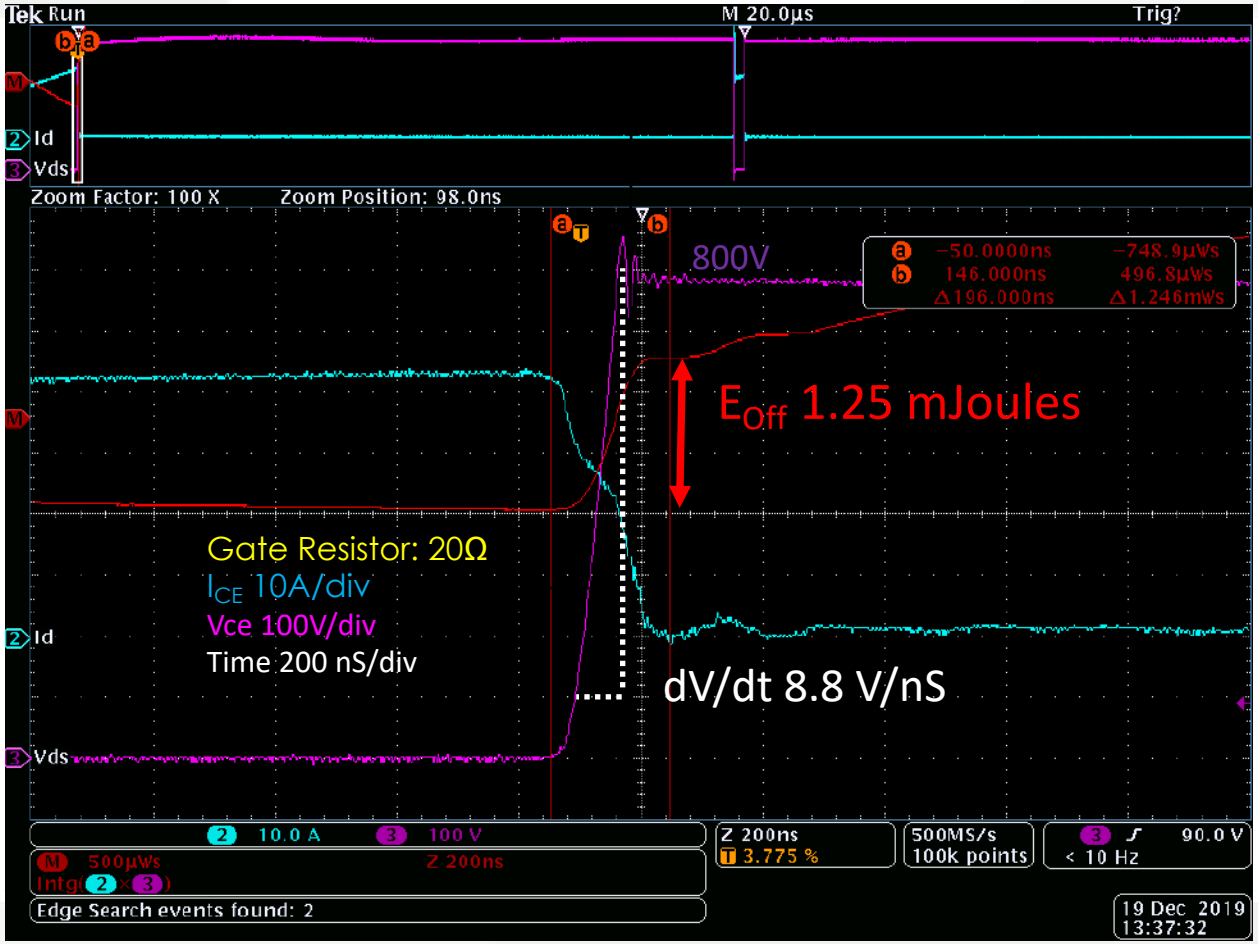
Pre-Switched



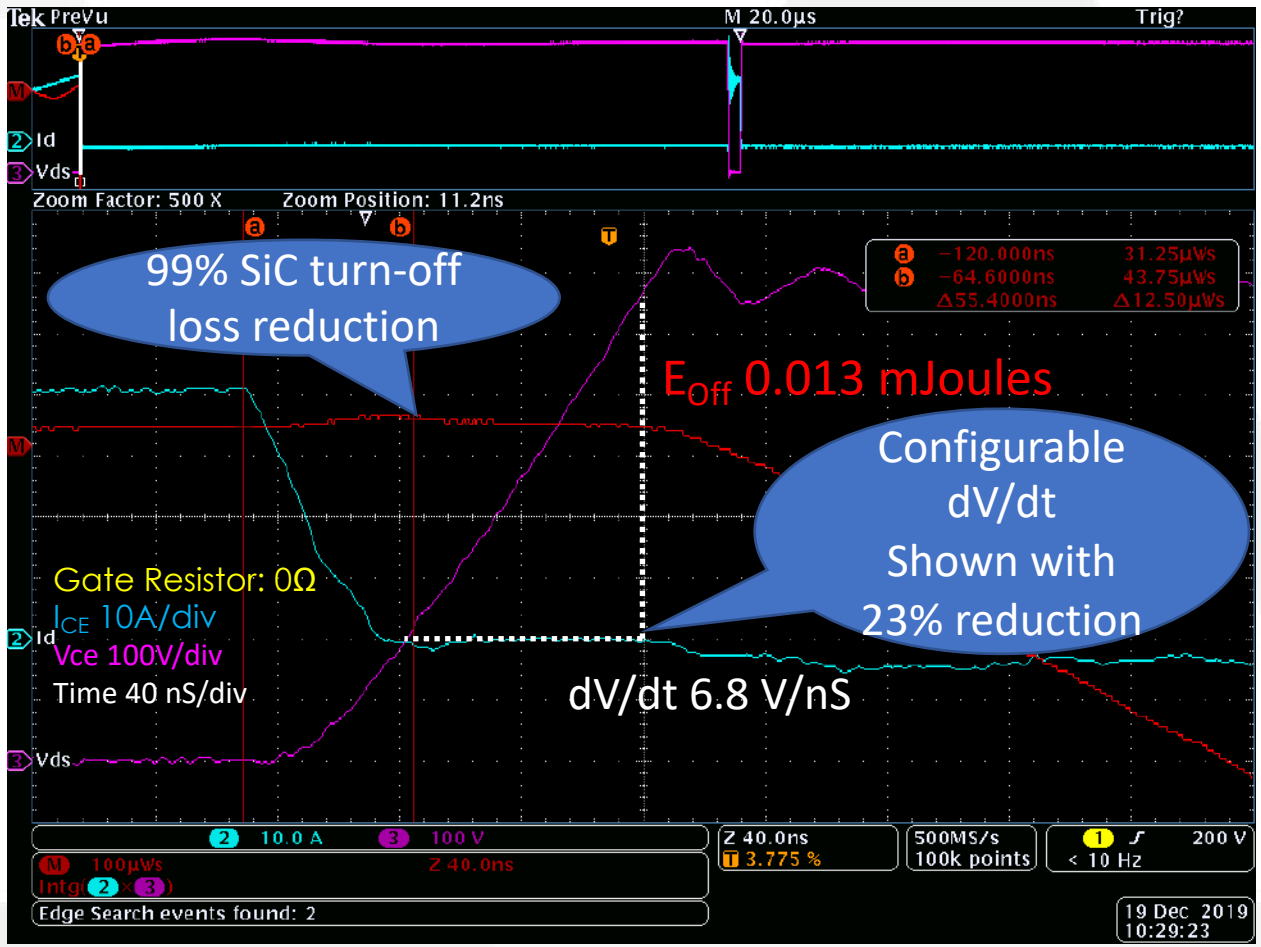
1200V 35 mOhm SiC MOSFET, Vbus = 800VDC, I Load =40A, 25C

Eliminates switching losses (SiC E_{off})

Hard Switched



Pre-Switched



Pre-Switch: Lowers dV/dt to virtually any value required while lowering turn off losses

1200V SiC 35mOhm MOSFET, 800VDC, I Load =40A, 25C

SiC switching loss comparison

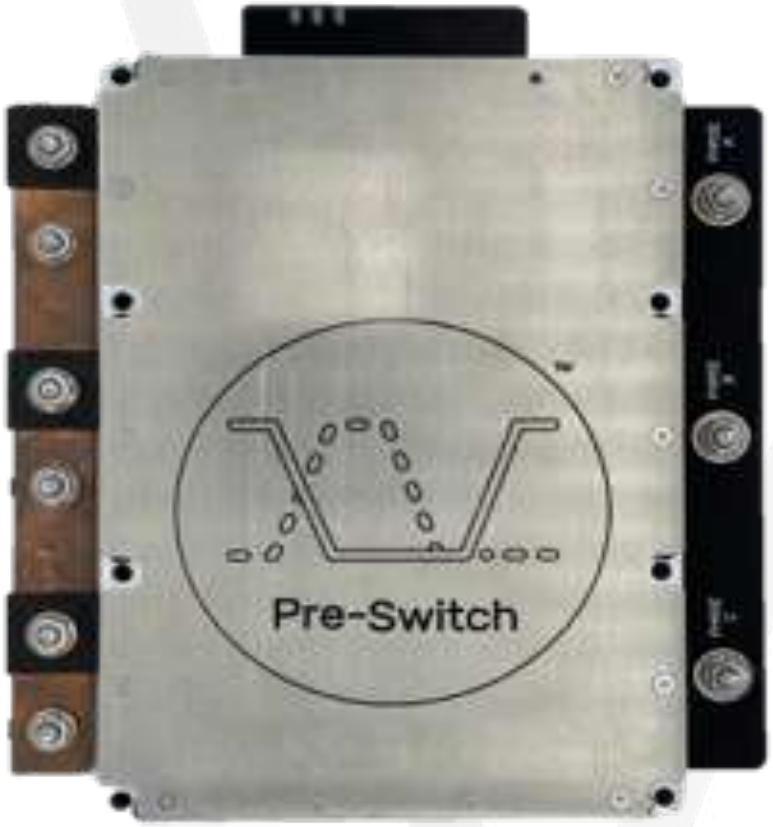
SiC MOSFET Double Pulse Test (UJ3C120040K3S, 800V, 40A RMS @25C)	**Pre-Switch** (Resonant losses)	**Pre-Switched** (Main device losses, (3 switches in parallel)	Hard-Switch (device losses, 3 switches in parallel)	Savings
Rg on (per device)		0.17Ω,	1Ω	
Rg off (per device)		0.17Ω	20Ω	
Turn On Energy (mJ)	0.218	0	7.539	100.0%
Turn Off Energy (mJ)	0	0	3.738	100.0%
Total (mJ)	0.218	0	11.277	100.0%
Total with overhead losses (mJ)	0.218	0	11.277	98.1%

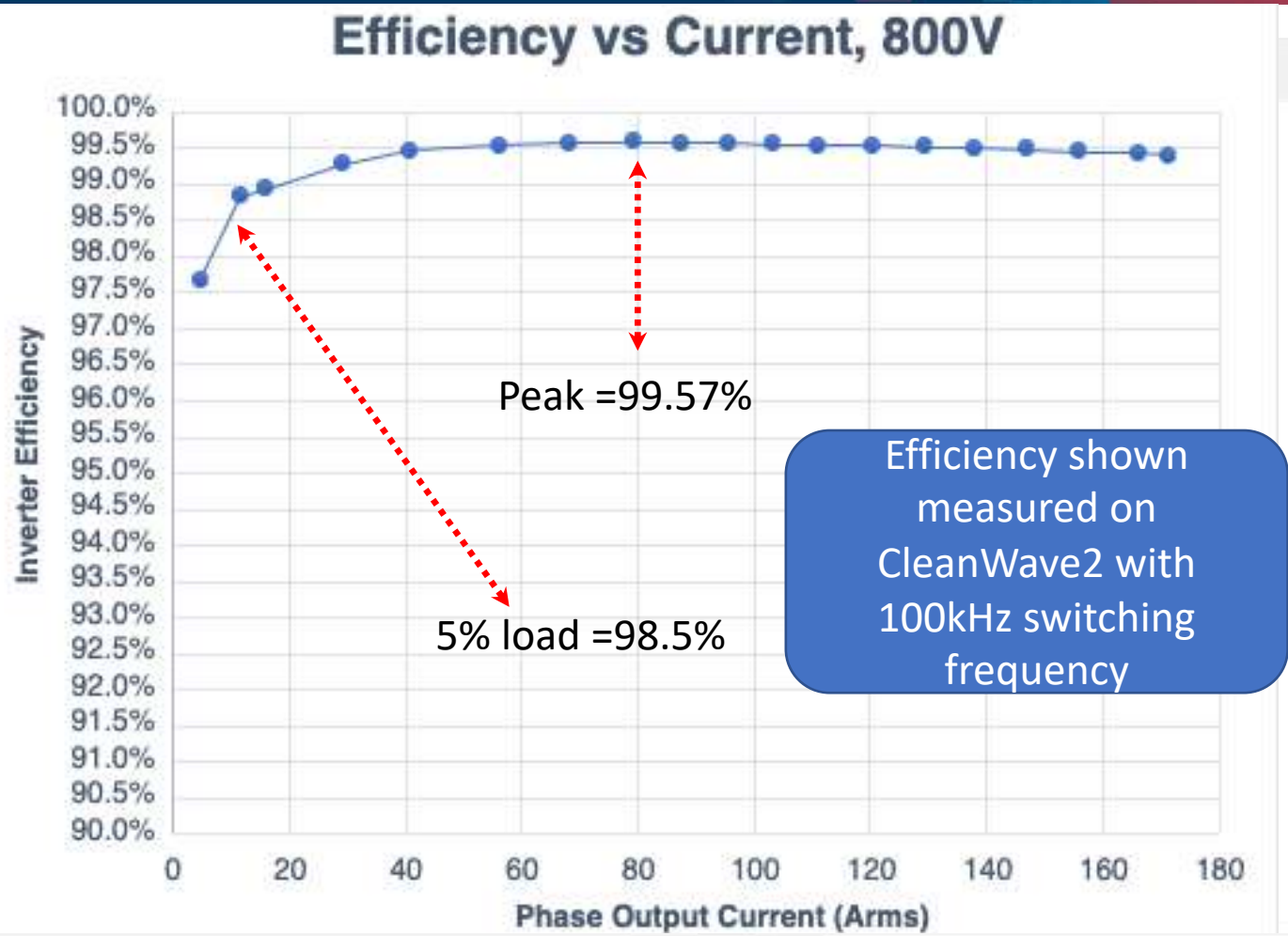
NOTE: IGBT switching loss reduction ~68-80%

Measured on CleanWave gen 1

CleanWave2 efficiency

Pre-Switch CleanWave2 reference inverter



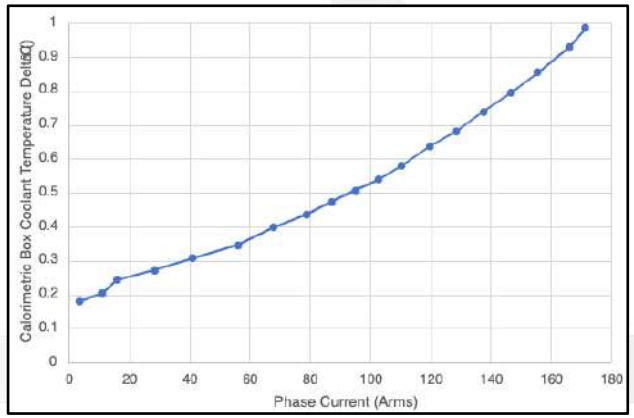


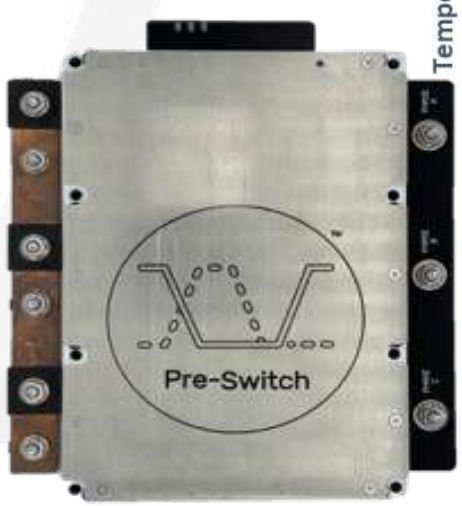
RMS

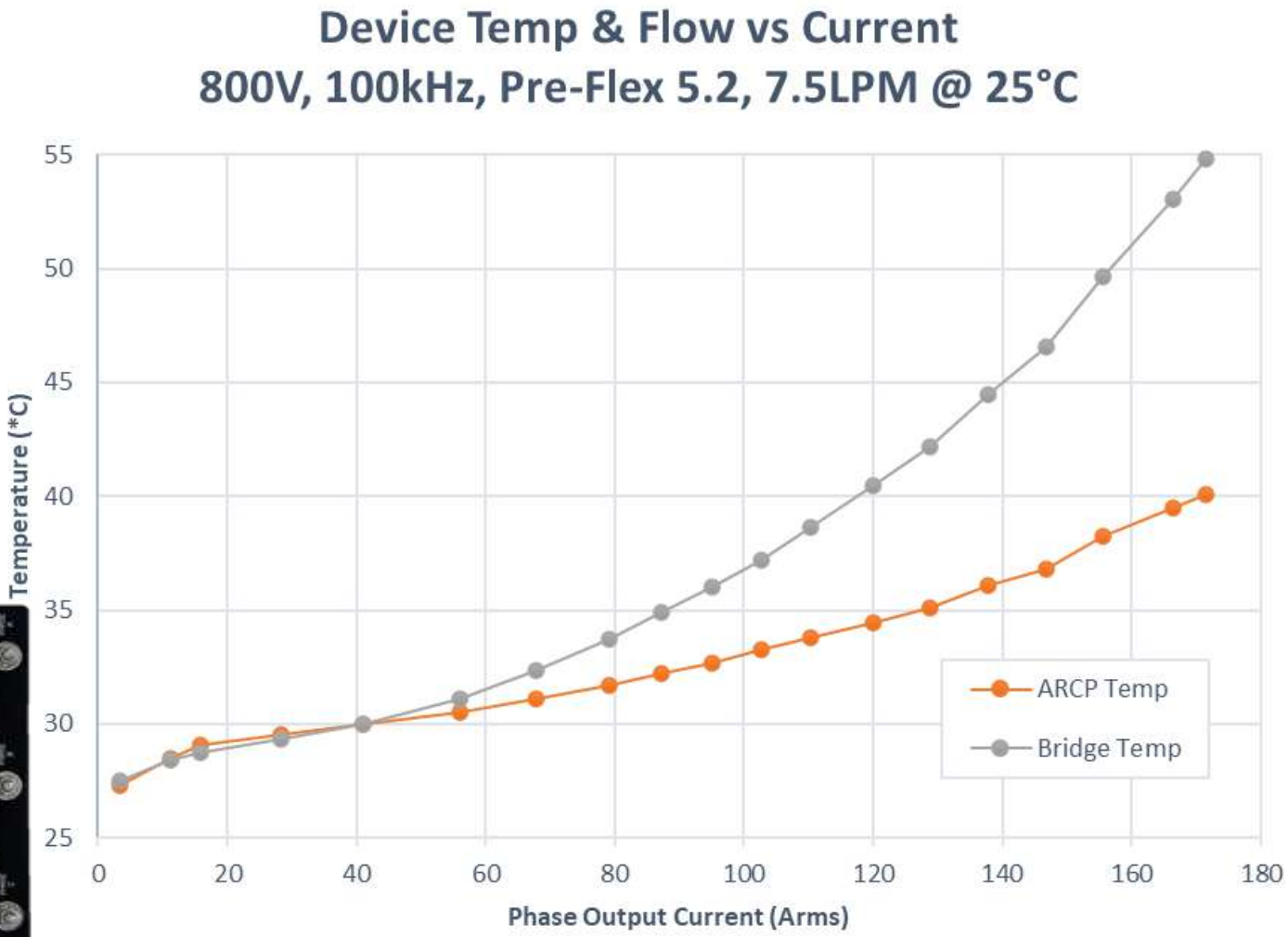
SiC FET temp at 180kW 27 degrees above coolant @ 7.5 Liter/per minute

CleanWave2 device temperatures

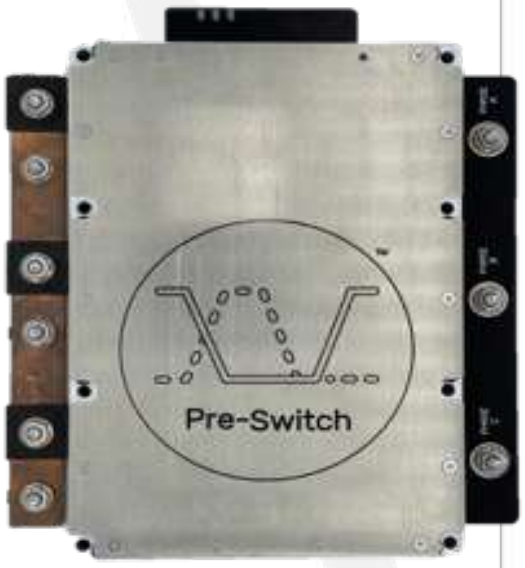
- Bridge transistor losses and ARCP losses are conduction losses only
- Coolant flow rate 7.5 LPM
  - 25°C coolant flow rate
- ARCP losses
  - Half voltage switched at zero current
  - Turn off and conduction losses only

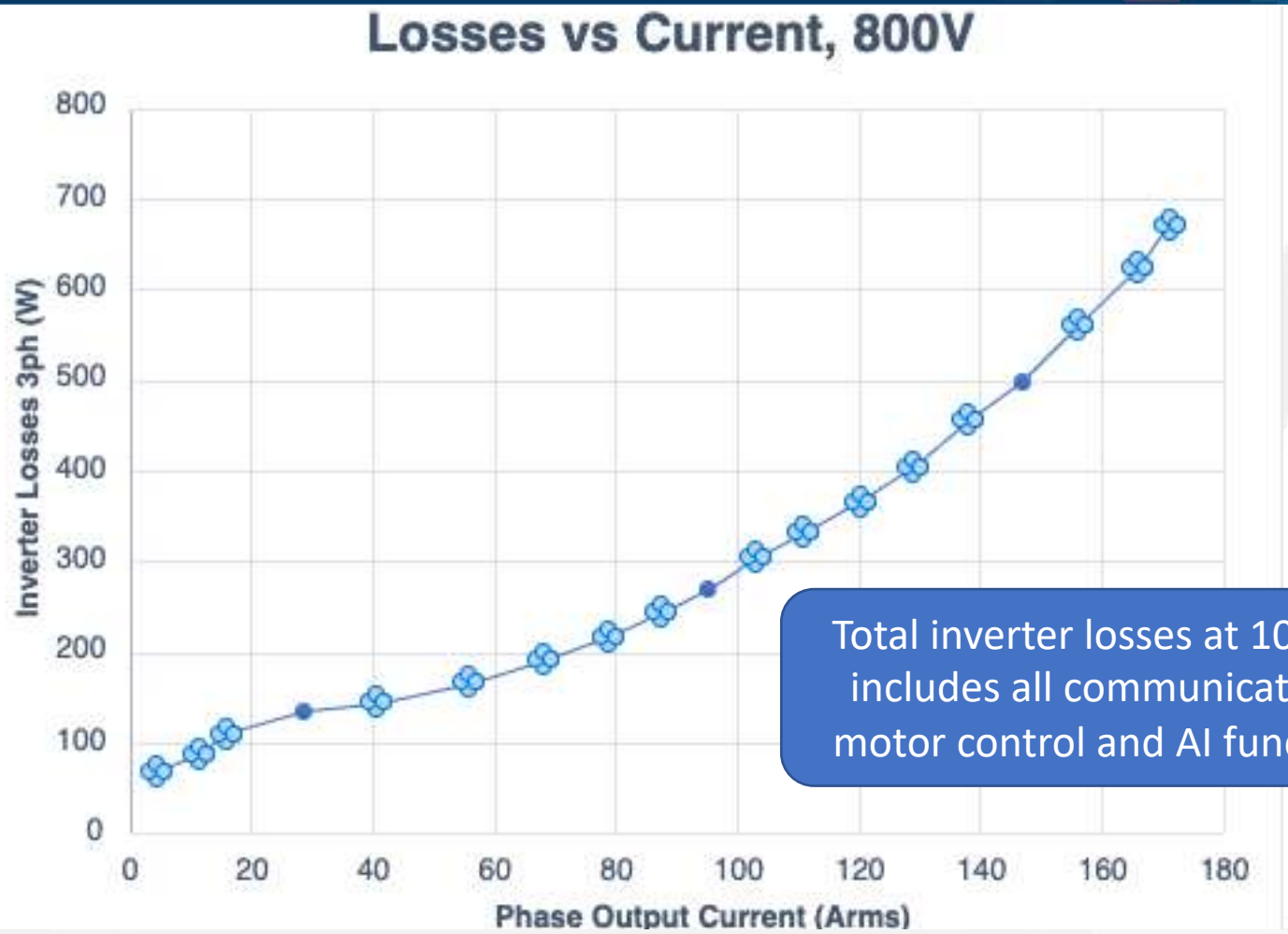






CleanWave2 losses



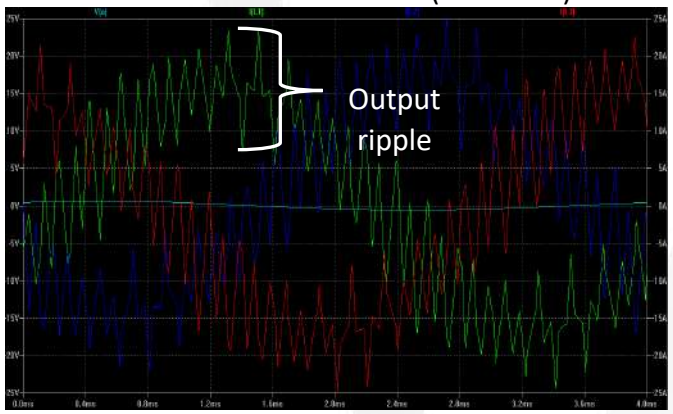


Total inverter losses at 100 kHz includes all communications, motor control and AI functions

100kHz Fsw motor benefits

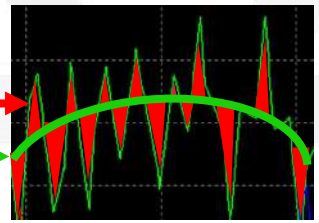
- Improves motor efficiency, range and reliability
  - Reduced inverter output ripple
  - Reduced common mode noise / bearing electrical etching
  - Reduced iron losses and eddy currents
  - Low dV/dt increases insulation reliability
- Enables lower cost/lighter low inductance motors

Hard Switched IGBT* (Fsw 5KHz)

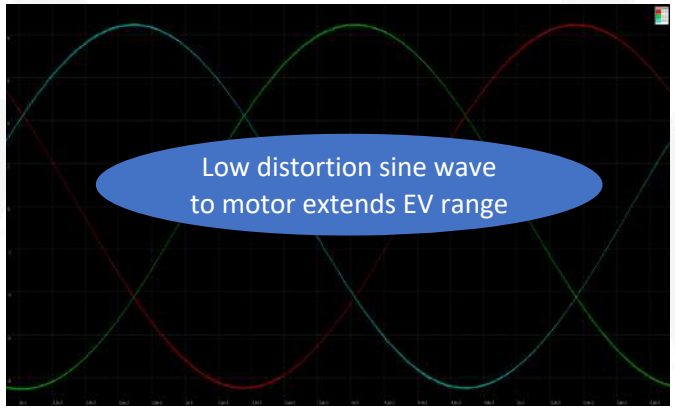


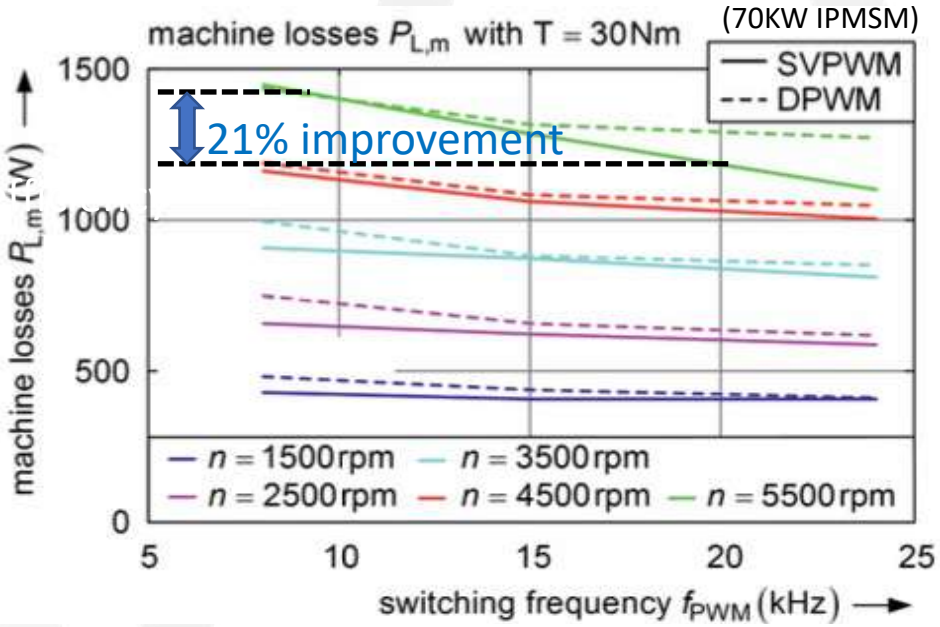
Induction heating in motor (efficiency loss)

Motor fundamental



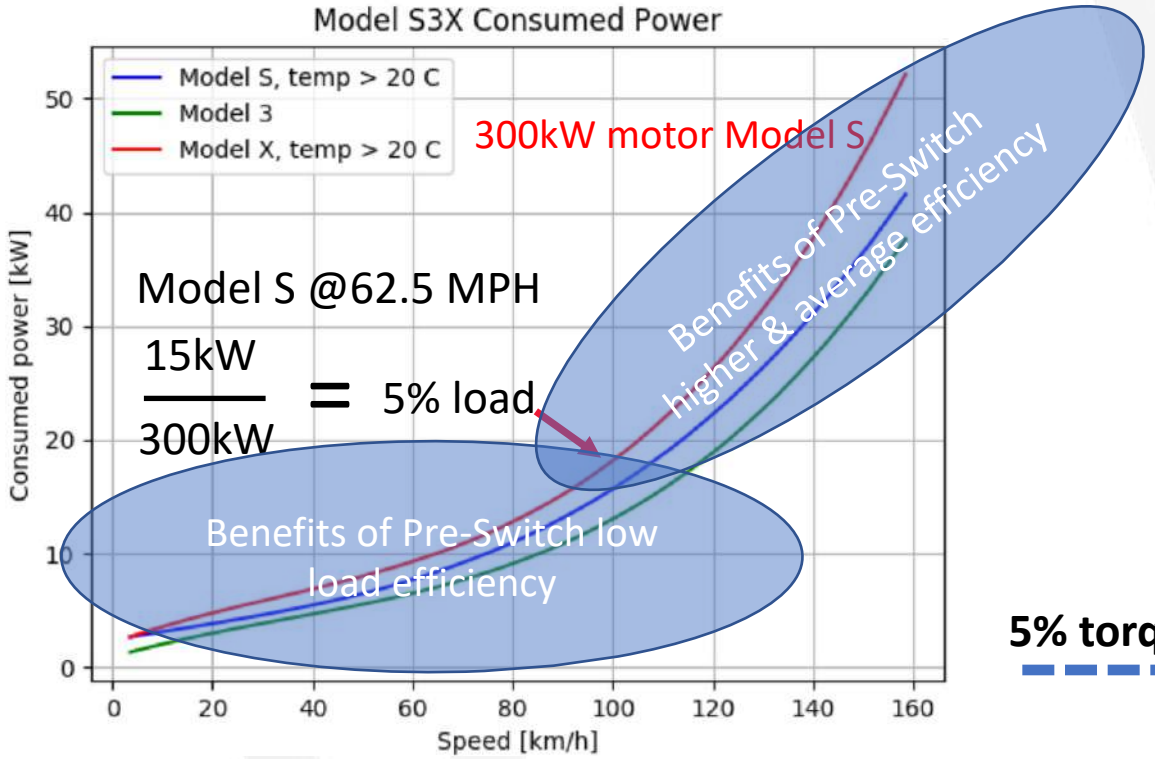
Pre-Switched SiC (Fsw 100KHz)





M. Luh, T. Blank and M. Weber, "Comparison and Evaluation of Modular Multilevel Converter Topologies for Li-Ion Battery Systems," *PCIM Europe 2017; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management*, Nuremberg, Germany, 2017, pp. 1-8.

Range improvements



250kW Permanent magnet motor

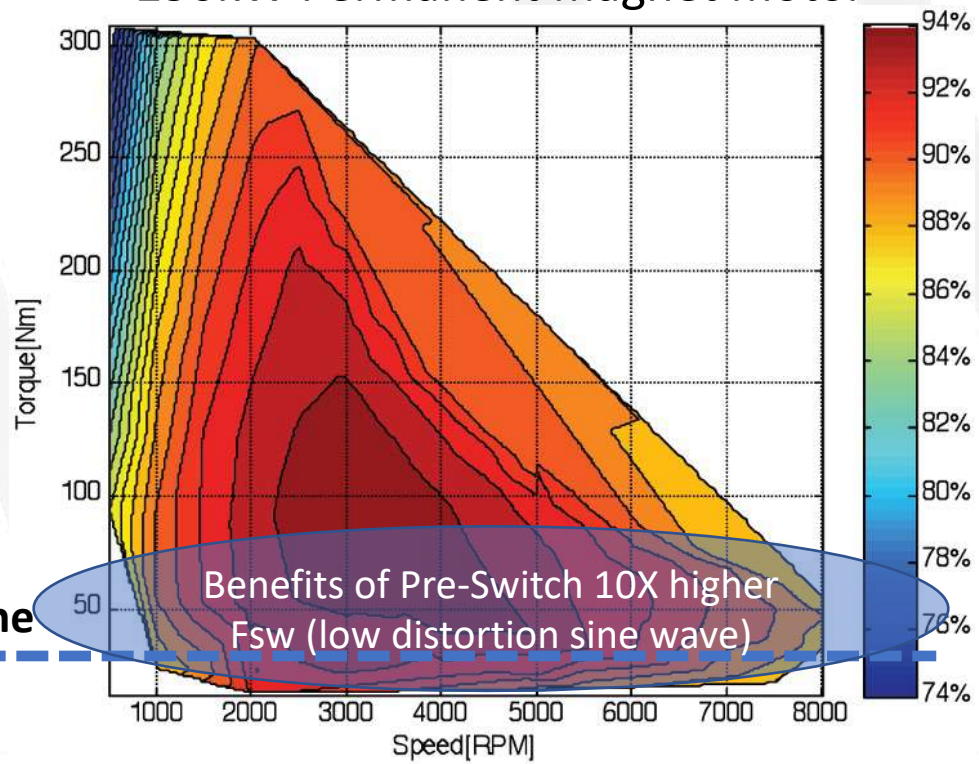
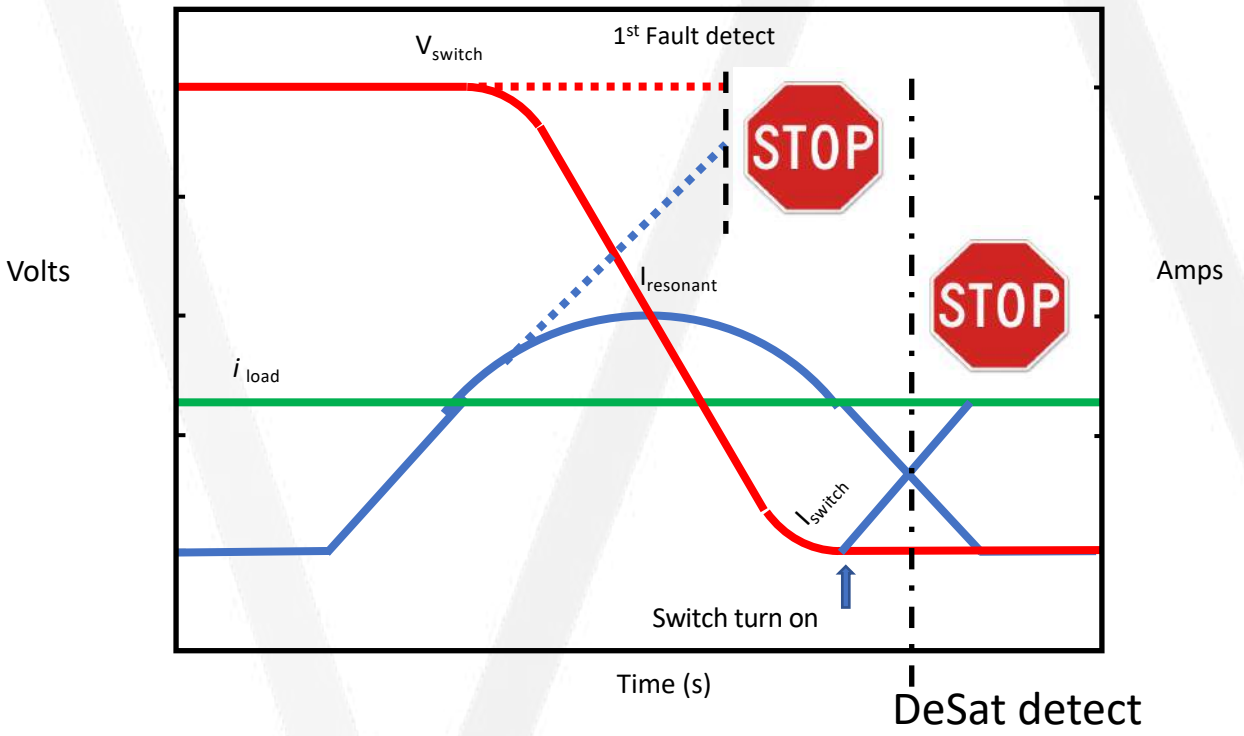


Image: HVH250 electric motor torque curve
Credit: BorgWarner

Safety benefits

- AI manages events prior to the main switches turning on
  - Detect faults early
  - Fast fault detection of any switch stops all switching -preventing DC bus short circuit
  - Fast current detection in resonant transition happens prior to main switch turn-on
  - Shorter blanking time (due to no ringing) adds safety margin for SiC MOSFETs & IGBTs

Double protection with **Pre-Switch**

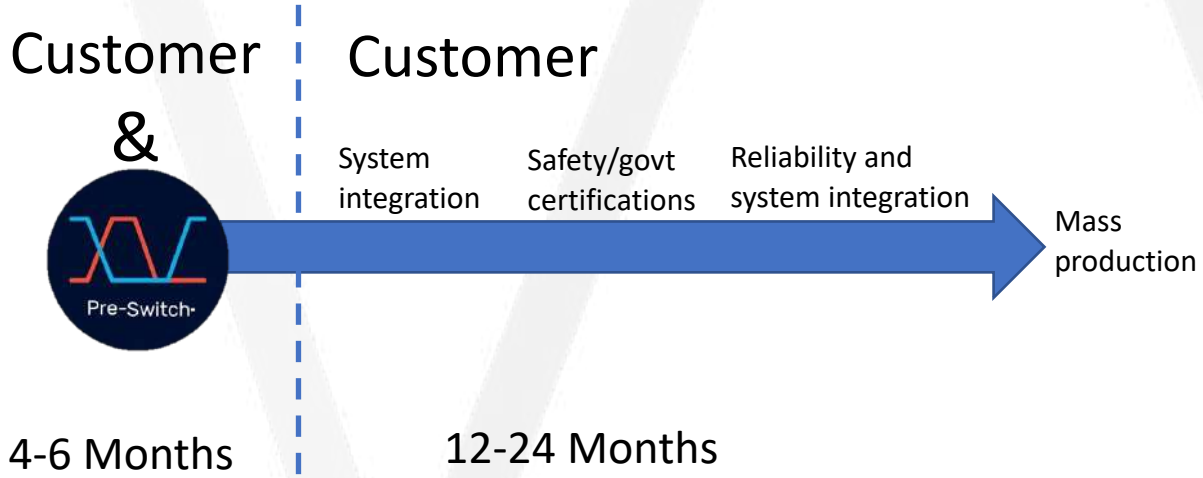


Business model

- Step 1: Customer onsite evaluation
  - Customization of CleanWave for customer's Dyno
  - Schedule Pre-Switch engineers with CleanWave
  - 4 days testing at 50 & 100 kHz
- Step 2: Development Program includes:
  - Pre-Switch Inverter Development Kit
  - IP License
  - Industry expert training and support
  - Chip, SW and support sold by project size
- Exclusivity available for certain markets

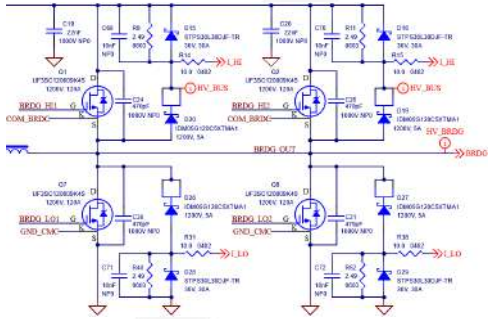
Pre-Switch Inverter Development Kit

CleanWave2 Schematics, layout, BOM, step files
Resonant tank selector tool
Pre-Switch Development System (PDS) 2.0 with DeepView
Pre-Switch Pre-Tune (optional motor control)
Pre-Switch DPT schematic for customer's power module



Development

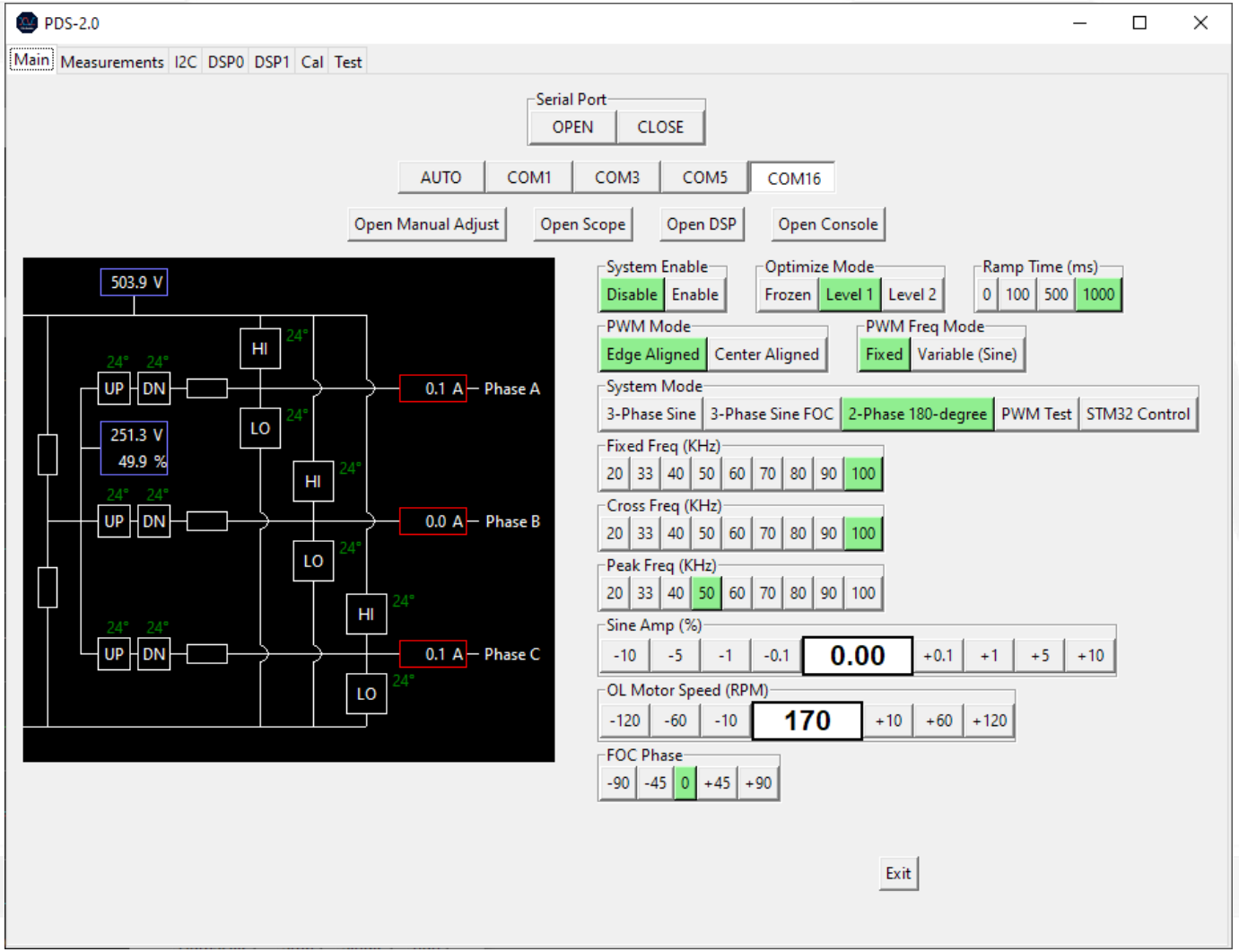
- Industry experts
- Reference designs
- Development tools
- Inhouse Motor control
- ARCP optimization tool
- DeepView internal digital oscilloscope
- DeepFlow external data streaming
- In-house dynamometer
- Communications customization



Pre-Switch lab: 250kW 3 Phase AC/DC PSU & Dynamometer

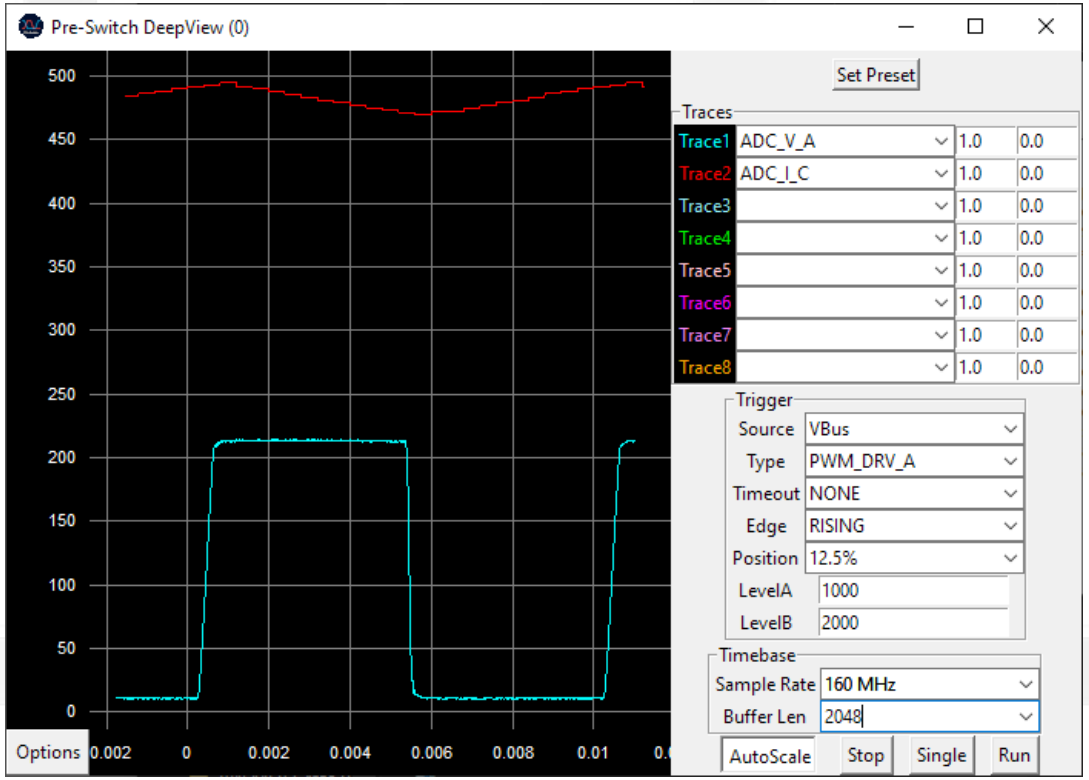
Pre-Switch Development System -2.0 (PDS)

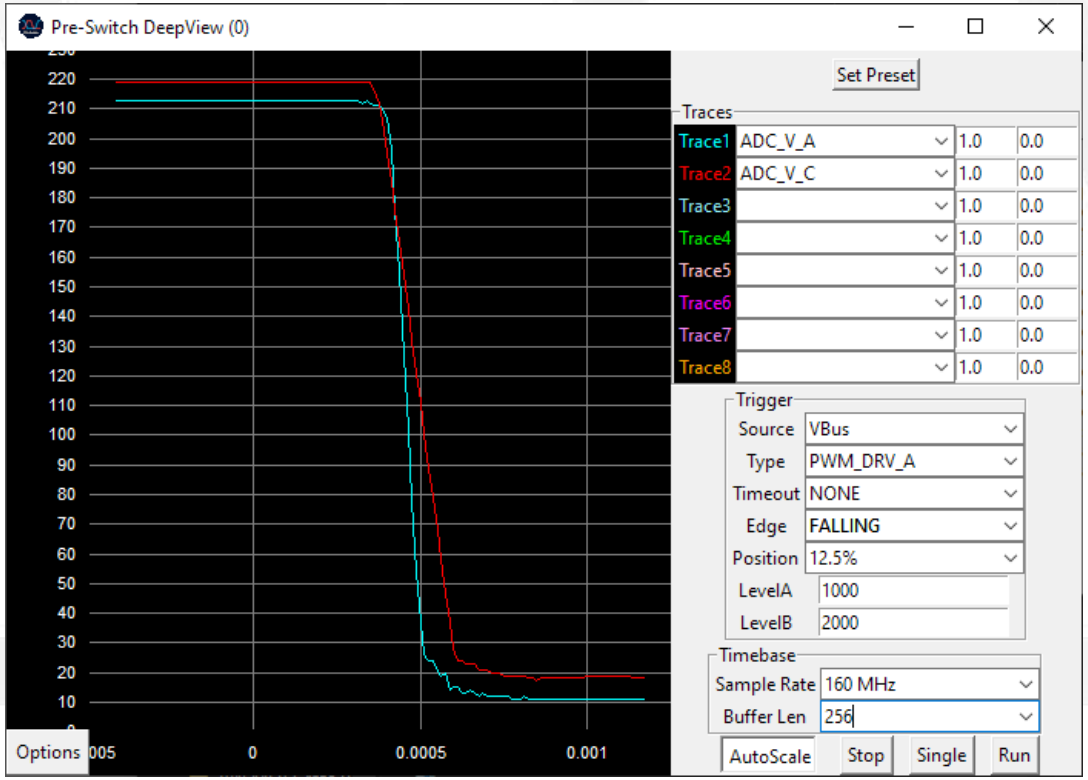
- Pre-Switch Development System 2.0 (PDS) :
  - Controls Pre-Switch inverter reference design
  - Controls customer's inverter
  - Allows fine tuning of parameters and calibration
  - Initial bring up assistance
  - Access to DeepView diagnostics
  - Real time monitoring with DeepFlow
  - Full Remote support



DeepView (within PDS 2.0)

- Integrated digital oscilloscope within Pre-Flex (Gen 5)
- Diagnostics, timing analysis, and remote customer diagnostic support
- 16 channel 160 MSPS capability with 2048 samples
- Programable triggers

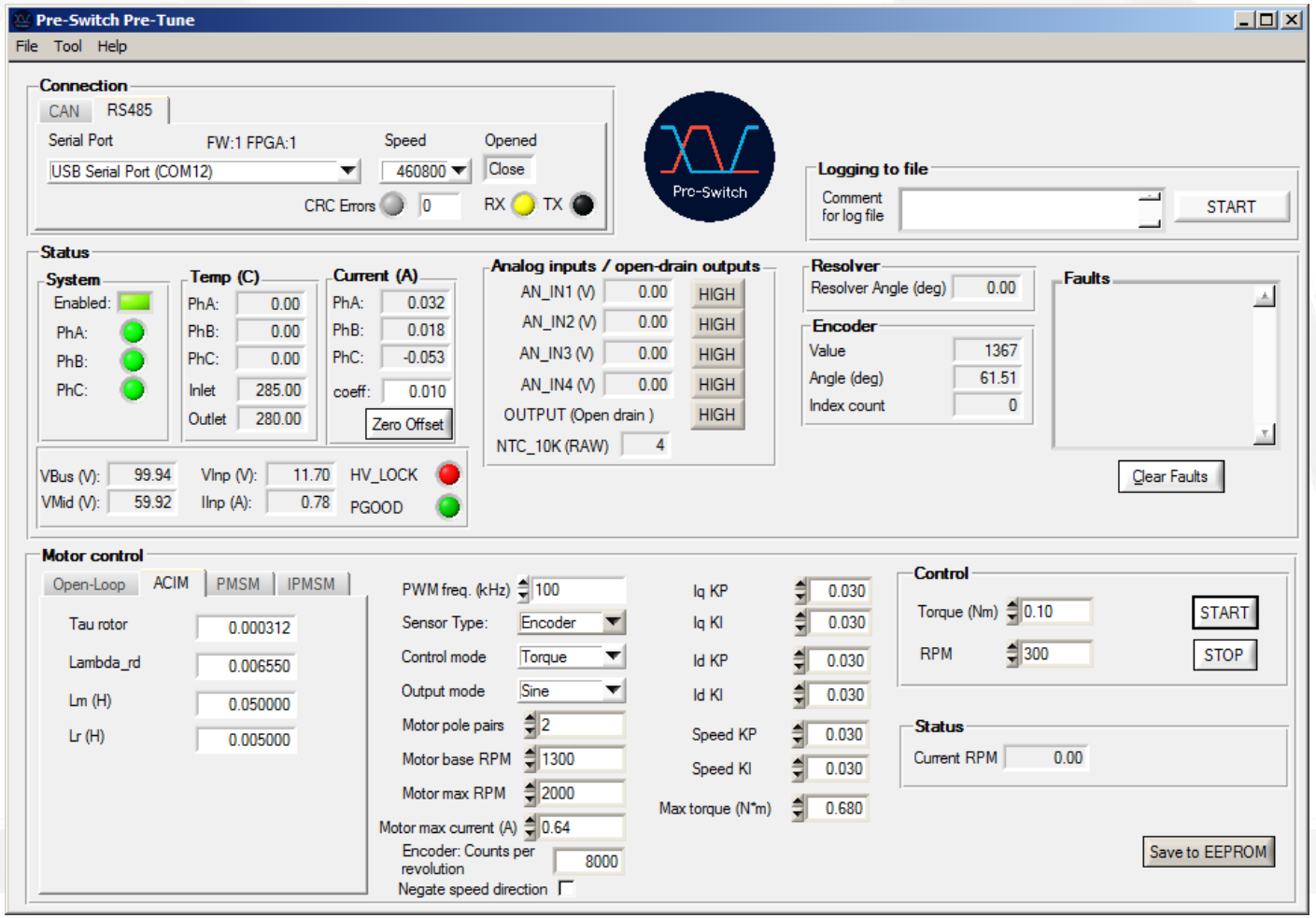




Pre-Tune

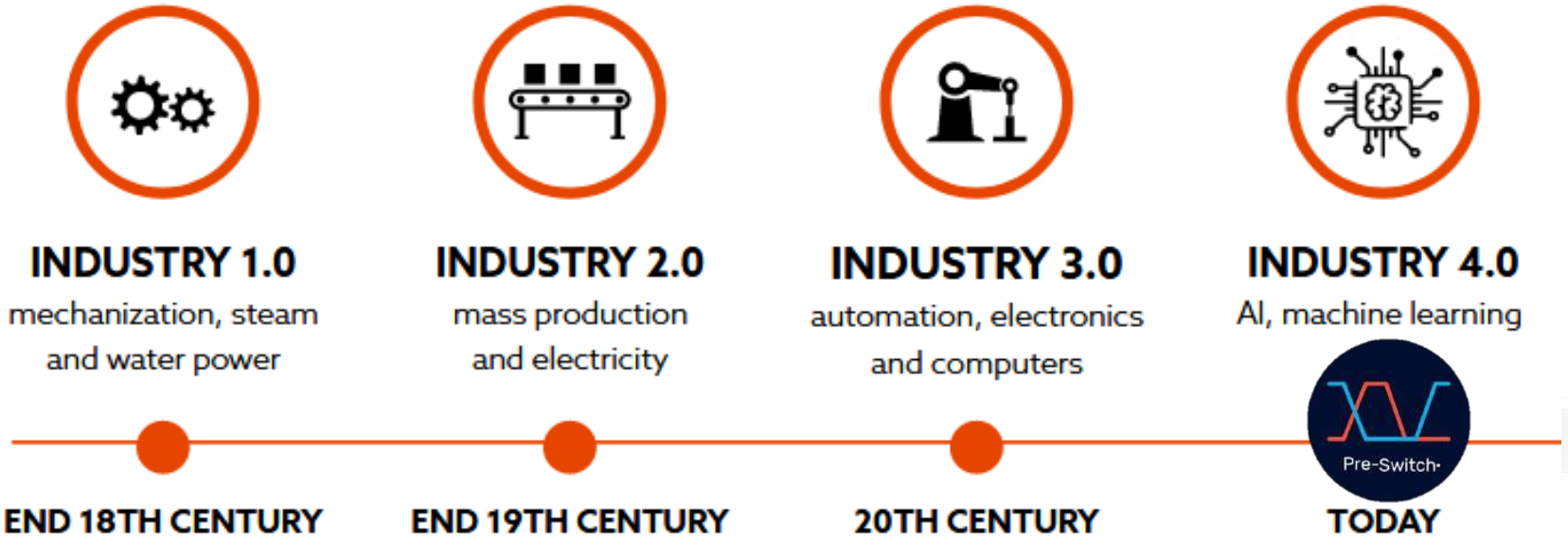
- Motor control and development
- Parameter detection
- Support for motor control
- CAN bus configuration
- RS485 connection

Pre-Switch lab: 250kW 3-Ph AC/DC PSU & Dynamometer



Pre-Switch, Inc.

- Paradigm shift for EV OEMs and Tier-1's
- Valuable efficiency differentiation for EV leadership
- Validated efficacy
- Active paying customers

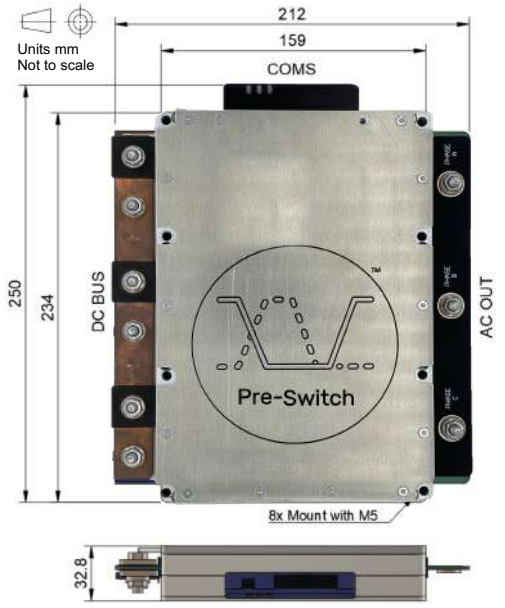


Appendix

CleanWave 100kHz Inverter 250 kW

Pre-Switch

The CleanWave inverter is a high power, compact and light-weight soft-switching intelligent reference system optimized to drive electric motors with a "clean" sine wave output resulting from it's 100kHz switching frequency operation. Engineers can quickly develop. Inverters with improved motor efficiency gains at 100kHz without adapting their motor control. The CleanWave2 uses Pre-Switch's newest 5th Gen Pre-Flex™ AI soft-switching algorithm for unparalleled adaptable soft-switching efficiency and safety. A peak efficiency of > 99.5% at 100 kHz is achieved using only two discrete United SiC 1200V 9 mΩ SiC FETs per switch position. The inverter includes integrated Field-Oriented Control and a CAN bus interface. Customers may utilize their proprietary motor control if desired. Additionally, many safety and self-diagnostic features have been added for robustness and reliability.



Inverter Specifications

Parameter	Value
V_{bus} Operating	400 – 900 V_{dc}
V_{bus} Nominal	750 V_{dc}
Continuous Output Current	250 A_{rms}
Size and Volume	234 x 159 x 33 mm – 1.23 L
Weight[2,3]	2.8 Kg
PWM Frequency[3]	10 – 100 kHz
Baseplate Temperature Range[4]	0 – 80°C
DC Link Capacitance[5]	Internal

Control Specifications

Parameter	Value
CAN Bus	Standard
Resolver/Encoder input	Standard
System DC Power	10-20 V
Protection	Integrated
3 PWM inputs (RS422 voltage levels)	Custom order

[1] Operating for 30 seconds or less, depends on modulation type and cooling
[2] With flat baseplate option
[3] External dc link capacitance required for < 50 kHz PWM frequency
[4] Derate after 60°C
[5] Low inductance interdigitated dc link bus bars (< 2nH) to allow resonant free external dc link capacitors if needed

Highlights:

- Industry leading power density >203 kW/L (3.36 kW/in³)
- 5th Gen Pre-Flex™ SiC AI Algorithm
- >99.5% peak efficiency @ 100 kHz
- PMSM FOC control included – customer configurable
- Integrated variable PWM maximizes modulation index
- Dedicated CPU for customer's proprietary motor control
- Secure remote firmware update capability
- Internal V_{bus} and phase current measurements
- Includes protection for
  - Overvoltage
  - Overcurrent
  - Over temperature
  - External DC link capacitor resonance
- Dust proof and designed for 50G
- No internal DC link EMI filter required
- Bidirectional - DC/AC or AC/DC
- Three heatsink options: flat baseplate, fin array baseplate, or integrated cold plate
- Optional DC bus bar assembly (shown above)
- Very low conducted and radiated EMI

www.pre-switch.com
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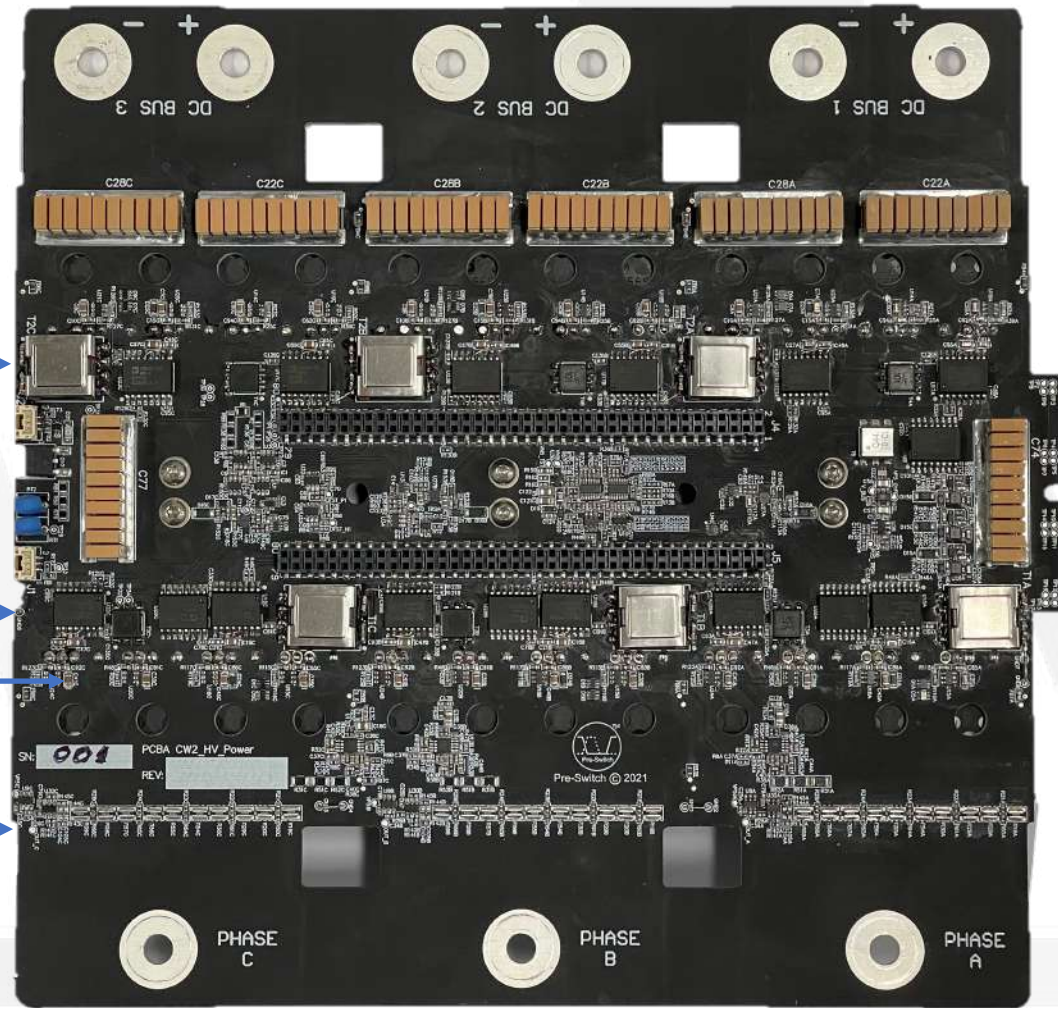
V5

Reference system details



Pre-Flex product brief

Pre-Flex SoC ICS10213

Soft-Switching AI

Pre-Switch

Preliminary

The ICS10213 is Pre-Switch's latest 5th generation Pre-Flex SoC is built on Microchip's SmartFusion2 SoC. This FPGA+ARM solution includes the firmware and DSPs necessary for full soft-switching optimization of a forced-resonant soft-switching architecture known as ARCP. The firmware requires analog to digital conversion of key inverter sensors to make timing decisions necessary to successful soft-switch power transistors at up to 100kHz.

Specifications

Parameter	Value
Pre-Switch Part Number	ICS10213
Package	VF400 BGA (17 x 17mm)
Base Part	Microchip M2S010-VFG400I
Rated Switching Frequency[1]	1 - 100kHz
Temperature	-40 ~ 100°C Industrial -40 ~ 125°C Automotive[2]
RoHS	Yes
ARM Core Frequency	136MHz
Input Clock Frequency	50MHz
FPGA Fabric Frequency	160MHz

Communication Specifications

Parameter	Value
CAN Bus Protocol	2.0B
CAN Baud Rate	0.02 ~ 1 Mbps
RS485	UART 460,800 Baud, 8N1
High Speed Serial Link	UART 6,000,000 Baud, 8N1
Serial Link to Additional ADC µC	UART 460,800 Baud, 8N1

[1] In 3 phase system
[2] Special order required
[3] Compared with 10kHz switching frequency
[4] Total sampling rate. If using multiple channels, sampling rate is divided per channel

Features / Benefits:

- 5th Gen Pre-Flex™ embedded AI soft-switching algorithm -> virtual elimination of switching losses in bridge transistors
  - Full soft-switching across all varying conditions, such as input voltage, load, temperature, device degradation and output frequency
  - Enables 10X higher switching frequencies[3] for high-speed motors and improved motor efficiency
- Optimized efficiency for all current levels using less transistor die area
- DeepView™ 16 channel integrated oscilloscope w/ complex triggering & 160 MSPS[4] simplifies debug and provides remote diagnostics
- DeepFlow™ real-time inverter analytic data
- Fast fault detection and reporting
- Fixed delay between PWM and switching edges simplifies motor control
- Variable frequency PWM -> improves modulation index
- Integrated dynamic dead time control improves modulation index
- Allows customer-specific motor control servo loops in dedicated DSP
- PWM control can be externally or internally generated
- Encrypted remote firmware update capability
- Includes protection for
  - Overvoltage
  - Overcurrent
  - Over temperature
  - External DC link capacitor resonance
- Encrypted remote firmware update capability

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Pre-Flex product brief

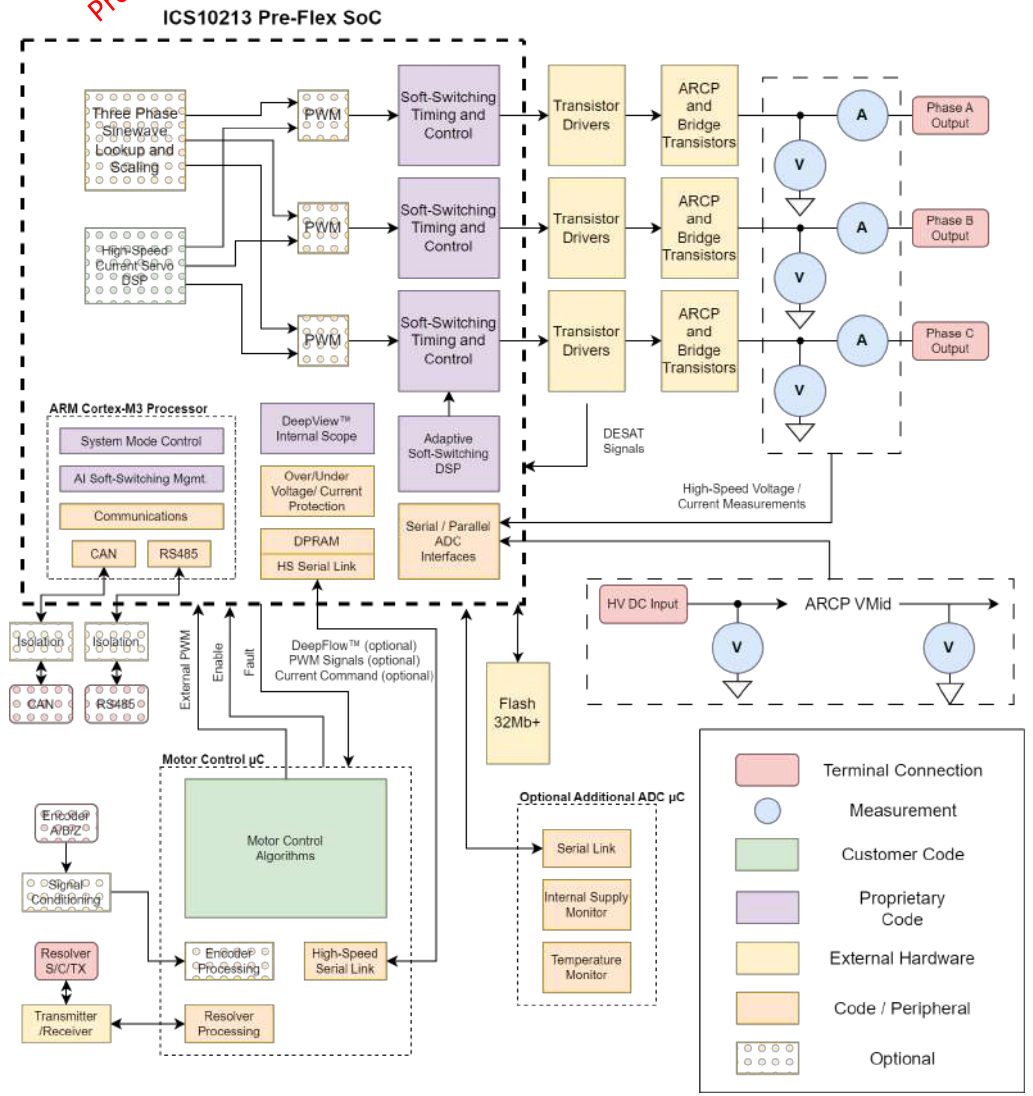
Pre-Flex ICS10213

Soft-Switching AI

Pre-Switch

Preliminary

Reference Application Block Diagram



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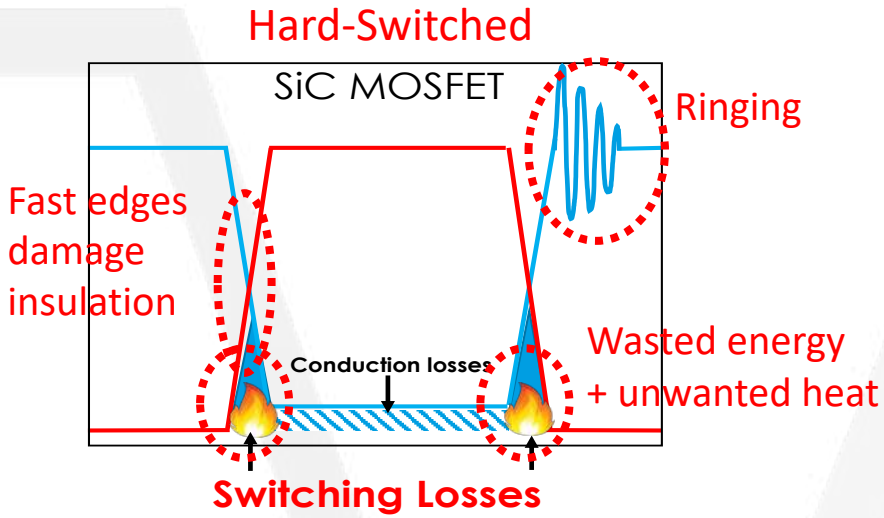
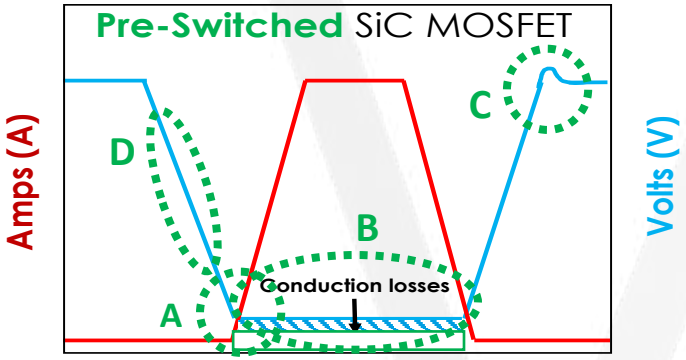
Pre-Switch benefit summary

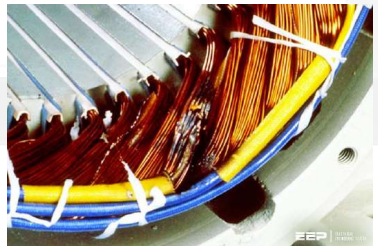




Virtually eliminates switching losses

- ~Elimination of transistor switching losses (A) -improves efficiency and allows high Fsw
  - Increase inverter Fsw w/virtually no efficiency penalty
  - Higher Fsw reduces inverter ripple current -improves motor efficiency
  - Reduces size/quantity of transistors needed for same efficiency/power -lowers cost
  - Reduces die temperatures lowers conduction losses -improves efficiency (B)
- Lossless configurable dV/dt filter solves fast edge speed problems in motor insulation & bearings (D)
- Extends paralleling of discrete component as alternative to power modules –saving money
- Allows low-cost Si IGBT to compete with SiC -lowers cost
- Reduces ringing that increases transistor stress, and which limits its working voltages (C)
- Enables SiC systems to switch 10-20X faster, IGBT 3-5X
- Operates outside of human audible range –eliminates cost of sound insulation
- Adds advanced/fast system safety features and system diagnostics at little or no cost
- AI generated current values eliminate second (redundant) current sensor needed
- Reduces conducted and radiated EMI costs
- Solves low cost SiC Cascode challenges to replace more expensive SiC MOSFET

D



- Elimination of transistor switching losses (A) -improves efficiency and allows high Fsw
- Increased inverter Fsw w/virtually no efficiency penalty
- Reduces amount/quantity of transistors needed for same efficiency/power -lowers cost
- Reduced die temperatures lowers conduction losses -improves efficiency (B)
- Higher Fsw reduces inverter ripple current -improves motor efficiency
- Reduces ringing that increases transistor stress, and which limits its working voltages (C)
- Enables SiC systems to switch 10-20X faster, IGBT 3-5X
- Allows low-cost Si IGBT to compete with SiC -lowers cost
- Solves dV/dt problems of SiC/IGBT induced motor bearing and insulation problems (D)
- Extends paralleling of discrete component as alternative to power modules –saving money
- Operates outside of human audible range –eliminates cost of sound insulation
- Adds advanced/fast system safety features and system diagnostics at little or no cost
- AI generated current values eliminate second (redundant) current sensor needed
- Integrated Discontinuous PWM
- Solves challenges enabling low cost SiC Cascode instead of more expensive SiC MOSFET